What is Claimed:

1. A near-field scanning optical microscope (NSOM) for laser machining a feature on a surface of a microstructure workpiece using an ultrafast laser source, the NSOM comprising:

the ultrafast laser source to generate pulses of laser light having pulse durations less than 1 ns and a peak wavelength;

an NSOM probe having a substantially cylindrical shape, the NSOM probe including:

an input plane at one end of the NSOM probe;

a probe tip at another end of the NSOM probe with a cross-sectional area less than a square of the peak wavelength of the pulses of laser light;

an optically transmissive core extending substantially from the input plane to the probe tip, the optically transmissive core portion being optically coupled to the ultrafast laser source through the input plane; and

a radiation confinement coating formed on a section of a side surface of the NSOM probe adjacent to the probe tip;

an NSOM mount to controllably hold the NSOM probe and the microstructure workpiece, the NSOM mount including;

an XY motion stage coupled to one of the NSOM probe or the microstructure workpiece; and

a Z motion stage coupled to one of the NSOM probe or the microstructure workpiece;

an NSOM probe monitor coupled to the NSOM mount for determining a distance between the probe tip of the NSOM probe and the surface of the microstructure workpiece;

an NSOM controller coupled to the NSOM probe monitor, the XY motion stage, and the Z motion stage, the NSOM controller controlling;

a vertical position of the one of the NSOM probe or the microstructure workpiece coupled to the Z motion stage based on the distance between the probe tip of the NSOM probe and the surface of the microstructure workpiece determined by the NSOM probe monitor; and

a horizontal position of the one of the NSOM probe or the microstructure workpiece coupled to the XY motion stage based on the feature to be laser machined on the surface of the microstructure workpiece.

2. The NSOM according to claim 1, further comprising:

an optical fiber optically coupled to the ultrafast laser source to transmit the pulses of laser light to the NSOM probe;

wherein the input plane of the NSOM probe has an input area approximately equal to a cross-sectional area of the optical fiber.

3. The NSOM according to claim 2, wherein:

the optical fiber has a fiber core that is formed of a waveguide material that has low absorptivity near the peak wavelength of the pulses of laser light.

4. The NSOM according to claim 1, wherein the ultrafast laser source includes at least one of:

a harmonic generating crystal to reduce the peak wavelength of the pulses of laser light;

a shutter coupled to the NSOM controller to control laser machining of the feature;

an attenuator coupled to the NSOM controller to control laser machining of the feature; or

a polarization controller for controlling a polarization of the pulses of laser light generated by the ultrafast laser source to be circularly polarized.

5. The NSOM according to claim 1, wherein the peak wavelength of the pulses of laser light is less than about 400 nm.

6. The NSOM according to claim 1, wherein the pulse duration of the pulses of laser light is less than about 20 ps.

7. The NSOM according to claim 1, wherein the probe tip of the NSOM probe has an elliptical cross-sectional shape.

8. The NSOM according to claim 1, wherein the optically transmissive core of the NSOM probe is formed of a waveguide material that has low absorptivity near the peak wavelength of the pulses of laser light.

9. The NSOM according to claim 1, wherein the radiation confinement coating has low absorptivity and high reflectivity near the peak wavelength of the pulses of laser light.

10. The NSOM according to claim 1, wherein the radiation confinement coating is formed of at least one of a metal layer or a dielectric layer.

11. The NSOM according to claim 1,

wherein the NSOM probe forms a substantially 90° bend between the input plane and the probe tip;

whereby a propagation direction of the pulses of laser light in the optically transmissive core of the NSOM probe is substantially bent 90° between the input plane and the probe tip.

12. The NSOM according to claim 11, wherein the section of the side surface of the NSOM probe coated by the radiation confinement coating extends from adjacent to the probe tip to at least the substantially 90° bend.

13. The NSOM according to claim 1, wherein:

the XY motion stage is a piezo-electric XY motion stage; and

the Z motion stage is a piezo-electric Z motion stage.

14. The NSOM according to claim 1, wherein:

the NSOM mount further includes a cantilevered NSOM probe holder adapted to allow calibrated movement of the NSOM probe in response to atomic force between the probe tip of the NSOM probe and the surface of the microstructure workpiece; and

the NSOM probe monitor determines the distance between the probe tip of the NSOM probe and the surface of the microstructure workpiece based on the calibrated movement of the NSOM probe.

15. The NSOM according to claim 14, wherein:

the NSOM mount further includes an NSOM probe oscillator coupled to the cantilevered NSOM probe holder to generate a periodic oscillation of the NSOM probe in a direction substantially normal to the surface of the microstructure workpiece; and

the calibrated movement of the NSOM probe in response to atomic force between the probe tip of the NSOM probe and the surface of the microstructure workpiece is a change in at least one of;

a period of the periodic oscillation of the NSOM probe; or

an amplitude of the periodic oscillation of the NSOM probe.

16. The NSOM according to claim 15, wherein:

the amplitude of the periodic oscillation of the NSOM probe is in the range of 0 to 20nm.

17. The NSOM according to claim 14, wherein:

the NSOM probe monitor includes:

a light source to produce a substantially collimated beam of light;

a reflective planar surface coupled to one of the NSOM probe and the cantilevered NSOM probe holder to reflect the substantially collimated beam of light;

an optical detector having at least two detector regions to detect the reflected substantially collimated beam of light and generate signal based on an amount of light detected by each detector region; and

processing means to determine the distance between the probe tip of the NSOM probe and the surface of the microstructure workpiece based on signals generated by the optical detector.

18. The NSOM according to claim 1, wherein the NSOM probe monitor includes a force meter coupled between;

the NSOM mount; and

one of the NSOM probe or the microstructure workpiece.

19. A method for laser machining a feature on a microstructure workpiece using an ultrafast laser source and a near-field scanning optical microscope (NSOM), the method comprising the steps of:

a) mounting the microstructure workpiece in the NSOM;

b) determining a distance between a probe tip of an NSOM probe of the NSOM and a surface of the microstructure workpiece;

c) controlling the distance between the probe tip and the surface of the microstructure workpiece such that the distance is substantially equal to a machining distance;

d) using the ultrafast laser source to generate pulses of laser light having pulse durations less than 1 ns and a peak wavelength;

e) coupling the pulses of laser light into the NSOM probe;

f) coupling a near-field mode portion of the pulses of laser light through the probe tip of the NSOM probe and onto a near-field irradiated area of the surface of the microstructure workpiece corresponding to a location of the probe tip to laser machine the near-field irradiated area;

g) moving at least one of the NSOM probe or the microstructure workpiece such that the probe tip is scanned over a feature region of the surface of the microstructure workpiece corresponding to the feature while

repeating steps (b) and (c) to maintain the distance between the probe tip and the surface substantially equal to the machining distance; and

repeating steps (d), (e), and (f) to laser machine the feature on the surface of the microstructure workpiece.

20. The method according to claim 19, wherein the step of determining the distance between the probe tip of the NSOM probe and the surface of the microstructure workpiece includes detecting an atomic force between the probe tip and the surface.

21. The method according to claim 19, wherein the step of determining the distance between the probe tip of the NSOM probe and the surface of the microstructure workpiece includes:

b1) generating a periodic oscillation of the NSOM probe in a direction substantially normal to the surface of the microstructure workpiece;

b2) detecting at least one of;

a period of the periodic oscillation of the NSOM probe; or

an amplitude of the periodic oscillation of the NSOM probe; and

b3) determining the distance between the probe and the surface based on changes in the at least one of the period or the amplitude of the periodic oscillation.

22. The method according to claim 19, wherein the step of controlling the distance between the probe tip of the NSOM probe and the surface of the microstructure workpiece includes using a Z motion stage to control a vertical position of one of the NSOM probe or the microstructure workpiece based on the distance between the probe tip of the NSOM probe and the surface of the microstructure workpiece determined in step (b).

23. The method according to claim 19, wherein:

the machining distance is in the range of up to about half of the peak wavelength of the pulses of laser light; and

the distance between the probe tip of the NSOM probe and the surface of the microstructure workpiece is controlled in step (c) with a tolerance of less than 5nm.

24. The method according to claim 19, wherein:

the ultrafast laser source includes an ultrafast laser oscillator and an attenuator; and

step (d) includes the steps of:

d1) using the ultrafast laser oscillator to generate initial pulses of laser light having pulse durations less than 1 ns, the peak wavelength, and an initial fluence; and

d2) using the attenuator to control the fluence of the initial pulses of laser light, thereby producing the pulses of laser light having a predetermined near-field machining fluence.

25. The method according to claim 19, wherein:

the ultrafast laser source includes an ultrafast laser oscillator and a polarization controller; and

step (d) includes the steps of:

d1) using the ultrafast laser oscillator to generate initial pulses of laser light having pulse durations less than 1 ns, the peak wavelength, and an initial polarization; and

d2) using the polarization controller to adjust the initial polarization of the initial pulses of laser light to a substantially circular polarization, thereby producing the pulses of laser light.

26. The method according to claim 19, wherein:

the probe tip of the NSOM probe has an elliptical cross-sectional shape; and

step (f) includes;

f1) transmitting the near-field mode portion of the pulses of light through the probe tip of the NSOM probe;

f2) evanescently coupling the near-field mode portion of the pulses of light onto the near-field irradiated area of the surface of the microstructure workpiece, the near-field irradiated area having substantially the same elliptical cross-sectional shape as the probe tip.

27. The method according to claim 19, wherein:

the probe tip of the NSOM probe has a tip area less that a square of the peak wavelength; and

step (f) includes;

f1) transmitting the near-field mode portion of the pulses of light through the probe tip of the NSOM probe;

f2) evanescently coupling the near-field mode portion of the pulses of light onto the near-field irradiated area of the surface of the microstructure workpiece, the near-field irradiated area being substantially equal to the tip area of the probe tip.

28. The method according to claim 19, wherein laser machining the near-field irradiated area in step (f) includes at least one of:

ablating workpiece material of the microstructure workpiece in the near-field irradiated area;

laser-assisted chemical vapor depositing deposition material on the surface of the microstructure workpiece in the near-field irradiated area;

exposing photoresist on the surface of the microstructure workpiece in the near-field irradiated area;

changing an index of refraction of workpiece material of the microstructure workpiece in the near-field irradiated area;

altering a lattice structure of workpiece material of the microstructure workpiece in the near-field irradiated area; or

changing a chemical composition of workpiece material of the microstructure workpiece in the near-field irradiated area.

29. The method according to claim 19, wherein:

the ultrafast laser source includes an ultrafast laser oscillator to generate the pulses of laser light in step (d) and a shutter to control emission of the pulses; and

step (g) includes the steps of:

g1) moving the at least one of the NSOM probe or the microstructure workpiece to scan the probe tip over a portion of the surface of the microstructure workpiece including the feature region;

g2) opening the shutter when the probe tip is scanned over the feature region of the surface of the microstructure workpiece, thereby allowing laser machining of the feature; and

g3) closing the shutter when the probe tip is scanned over other scanned regions of the surface of the microstructure workpiece, thereby preventing laser machining of the other scanned regions of the surface of the microstructure workpiece.